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MODIFICATION OF AGGREGATE GRADING FOR POROUS ASPHALT

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ABSTRACT

In the 1970's, the fatality index on Malaysian roads exceeded 20. In 1991, a Cabinet Committee on Road Safety was set up to come up with measures to reduce the predicted number of deaths by 30% or translated into a fatality index of 3.14 by the turn of the century. Among the measures suggested included the application of porous asphalt. Up to now, a number of major trunk roads have been paved with porous asphalt. This paper describes the method used to modify a porous asphalt gradation from Korea to suit Malaysian quarry practic. The method involved fabricating porous mixes according to four trial gradations and comparing them with mix properties stipulated in the Korean specifications. The adopted gradation is a trade-off between mix stability and permeability. Samples using this gradation were prepared using 60/70 conventional bitumen and 1% Drain Asphalt Modified Additive (DAMA) and their design binder content determined from the results of the laboratory binder drainage and Cantabrian tests. The specimens were then evaluated for Marshall stability and resilient modulus at the design binder contents. The results indicate an improvement in mix properties with the addition of 1% DAMA.

Keywords: Aggregate gradation, porous asphalt, stability, permeability, binder drainage

1. INTRODUCTION

From 1986 to 1998, the average annual traffic growth on Malaysian roads was 7.4%(1). This phenomenal traffic growth exerts lots of pressure on the existing road network causing a sharp increase in traffic volume along major trunk roads and the subsequent accident rate. In the mid-1970's, the fatality rate on Malaysian roads exceeded 20, which was very high compared to similar values in developed nations. In 1991, a Cabinet Committee on Road Safety was set up and targeted to reduce the number of deaths by 30% or 3.14 fatality rate by the turn of the century, setting 1989 as the base year(2). Among the measures proposed and adopted to reduce accidents include finding alternative pavement materials to provide high skid resistant surfacings including porous asphalt. The first application of porous asphalt on Malaysian roads took place in 1991. In 1995, it was laid on the Federal Highway. The porous asphalt section along the Federal Highway carries some of the heaviest traffic and has recently been resurfaced with porous asphalt. In addition, the patchy application of porous asphalt along the North-South Highway is a unique experience to the country.

2. AGGREGATE GRADING DESIGN FOR POROUS ASPHALT

The scope of bituminous mix design encompasses aggregate grading design and the determination of the optimum binder content. In the past, the design of bituminous mixture is heavily biased towards the determination of the optimum bitumen content for a given bitumen type. This is probably due to the economic implications in a slight variation of mix binder content.

The design of aggregate gradation has largely been ignored. Typically, an aggregate grading is designed based on empirical methods. Earlier works on the subject matter by Fuller and Thompson(3), Hveem(4) and Nijboer(5) has shed some light on the subject matter. The gradation design based on the study of dry aggregate packing proposed by Lees(6) has been modified by Cabrera and Hamzah(7) to design porous mixes and the details has been presented elsewhere.

3. OBJECTIVES

1. To develop an aggregate gradation to suit Malaysian quarry practice by modifying a gradation developed in Korea.
2. To determine the design binder content of the modified gradation mix prepared using a conventional base bitumen grade 60/70 and base bitumen plus Drain Asphalt Modified Additive (DAMA)
3. To study the resilient modulus and Marshall stability of porous mixes prepared at the design binder content with and without DAMA.

4. METHODOLOGY

4.1 Trial Gradations

The original Korean porous asphalt gradation utilizes sieve sizes that are not conventionally used in Malaysian quarries. Hence, a gradation modification is essential to reduce production cost. It is a known fact that the proportion of fines in an aggregate gradation influences mix permeability and stability. Generally, mixtures with lower fine contents will exhibit higher permeability but lower stability compared to mixtures with higher fine contents. The methodology adopted to modify the gradation was based on a trade-off between stability and permeability.

Four trial gradations designated as G1, G2, G3 and G4, corresponding to 10%, 12%, 13% and 14% fines were adopted for further evaluation. Fine aggregate constitute those having size less than 2.36 mm. The particle size distributions of the trial gradation and the Korean gradation envelop are shown in Figure 1.

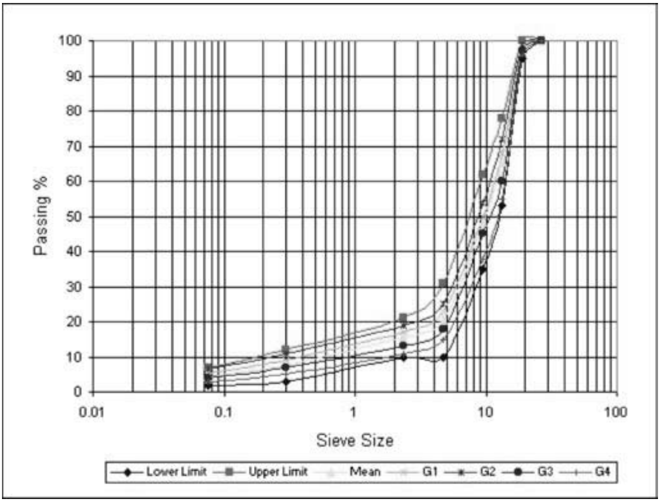

Figure 1: Particle Size Distributions of Korean and Trial Gradations G1, G2, G3 and G4

4.2 Mix Preparation

Mixes were prepared, with and without DAMA, based on the trial gradations at 5% binder content and 4.5% filler. A 60/70 pen bitumen was used as the conventional bitumen. Only 1% DAMA was blended dry with aggregates and binder corresponding to the DAMA proportion adopted in Korea. For mixes without DAMA, the aggregates and binder were respectively mixed and compacted at 140°C and 130°C using 50 blows per face of the Marshall hammer. Aggregates, binder and 1% DAMA by weight of total mix were mixed and compacted at 180°C and 165°C respectively using the same compaction mode and energy. After the specimen had cooled overnight and prior to extrusion, specimens were tested for permeability using a specially designed falling head water permeameter. In the permeability test, the time taken for water level to drop from one level to another level was noted and the coefficient of permeability was calculated using Equation (1).

$$k = 2.3\frac{aL}{At}\log\left(\frac{h_1}{h_2}\right) \qquad \text{Equation (1)}$$

Where k is the coefficient of permeability (cm/s), A, sample cross sectional area (cm^2) , L, height of sample (cm), a, tube cross sectional area (cm^2), t, time(s), h_1 and h_2 respectively the initial and final level.

After measuring specimen heights and knowing the dry weights, the specimens were tested for Marshall stability and flow at 60°C using the Marshall testing machine.

4.3 Balancing Permeability and Stability Requirements

Separate graphs relating stability and permeability for mixes incorporating 1% DAMA and mixes without DAMA versus fine contents were plotted to determine the percentage fines required to balance between stability and permeability requirements. Based on the laboratory results from mix prepared using the modified gradation, the adopted gradation should fulfill the following additional criteria(8):

(i) Porosity in excess of 20%.
(ii) Permeability not less than 0.01 cm/s.
(iii) Stability exceeding 5 kN.

The next step in the methodology involved the determination of the design binder content of the adopted gradation using 60/70 pen base bitumen and 60/70 pen base bitumen plus 1% DAMA.

4.4 Determination of Design Binder Content

The design binder content of the selected gradation was then determined based on the following tests:
(i) Cantabrian test for abrasion loss to determine the lower limit of the design binder content.
(ii) Binder drainage test to determine the upper limit of the design binder content.

In the Cantabrian test, a Marshall sample was subjected to 300 drum rotations in the Los Angeles drum. The abrasion loss was expressed in terms of the percentage mass loss compared to the original mass as illustrated in Equation (2). The test method adopted followed the procedure described by Jimenez and Perez(9). Specimens were tested at binder contents ranging from 3.0% to 5.0% in 0.5% increments at 29°C.

$$P = \frac{P1 - P2}{P1} \text{ x } 100 \qquad \text{Equation (2)}$$

Where P is the abrasion loss (%), P^1 and P^2 are respectively the initial and final mass in grams.

The binder drainage tests were conducted according to the TRL procedure as described by Daines(10). The binder contents and binder drainage test temperatures used are summarized in Table 1.

Binder Type	Binder Content (%)	Binder Drainage Test Temperature (°C)
Base 60/70	5.5, 6.0, 6.5 and 7.0	150
Base 60/70 + 1% DAMA	5.5, 6.0, 6.5 and 7.0	185

Table 1: Binder Content and Conditioning Test Temperature

The loose samples, starting with low binder contents, were placed in drainage baskets and conditioned in the oven at the designated test temperature for 3 hours. Underneath the baskets were pre-weighed drainage trays. At the end of the test, the mass of drained binder and filler was determined by difference. The percentage retained binder, R, was calculated from Equation (3).

$$R = 100 \times \frac{B\left[1 - D/(B + F)\right]}{1100 + B} \qquad \text{Equation (3)}$$

where D is the mass of binder and filler drained (g), B is the initial mass of binder in the mix (g) and F is the initial mass of filler in the mix (g).

4.5 Five-Pulse Indirect Tensile Resilient Modulus and Marshall Stability

The indirect tensile resilient modulus test was conducted using the Universal Asphalt Tester, MATTA. Each specimen was tested at 25°C after 4 hours conditioning. The samples were initially subjected to 5 condition pulses. A 1200 N peak load was applied along the vertical diameter of the sample. The pulse period and pulse width were respectively 3000 ms and 100 ms while the rise time was 50 ms. Linear variable differential transducers monitored the resultant indirect tensile strain along the horizontal diameter. Since the test is undestructive, upon completion of this test, the same specimen was tested for Marshall stability at 60°C in the standard manner.

5. RESULTS AND DISCUSSION

5.1 Selection of Modified Aggregate Gradation

The relationships between permeability versus percentage fines for mixes with and without DAMA are shown in Figures 2 and 3 respectively. The corresponding relationships between stability and fines content are graphically illustrated in Figures 4 and 5. As hypothesized, the permeability reduces but stability increases as the amount of fines in a mixture increases. Mixes that are deficient in fines has large interconnected voids that freely permit passage of water but lacking in strength. However, these voids are gradually filled up as the fine content increases which has the adverse effect of reducing mix permeability but on the other hand increasing mix stability.

To trade-off between permeability and stability, two tangent lines are drawn from the top and bottom portion of each curve. The point of intersection of the two lines locates the target percentage of fine aggregate. As shown in Figures 2 through 5 and tabulated in Table 2, the average target percentage fines equals 12.6%. Hence, the accompanying modified gradation, with 4.5% filler content, is shown in Figure 6. Mixes made with this modified gradation exhibit permeability, stability and porosity above the limiting values stipulated in the Korean specification.

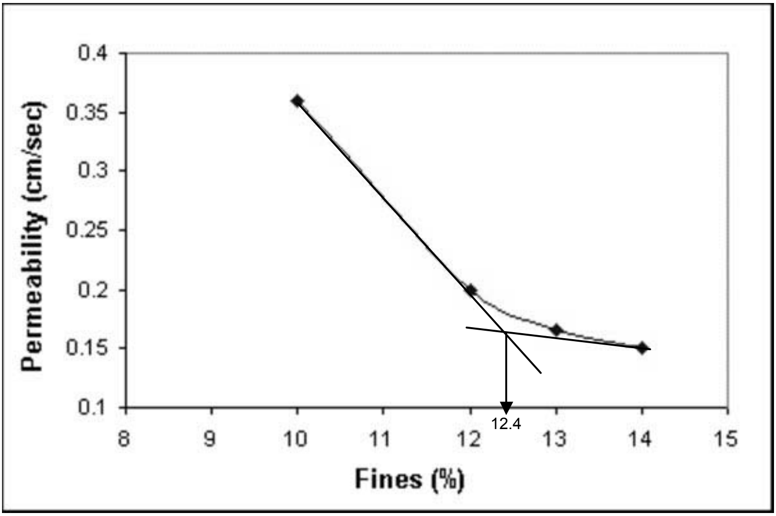

Figure 2: Permeability Test Result – With DAMA

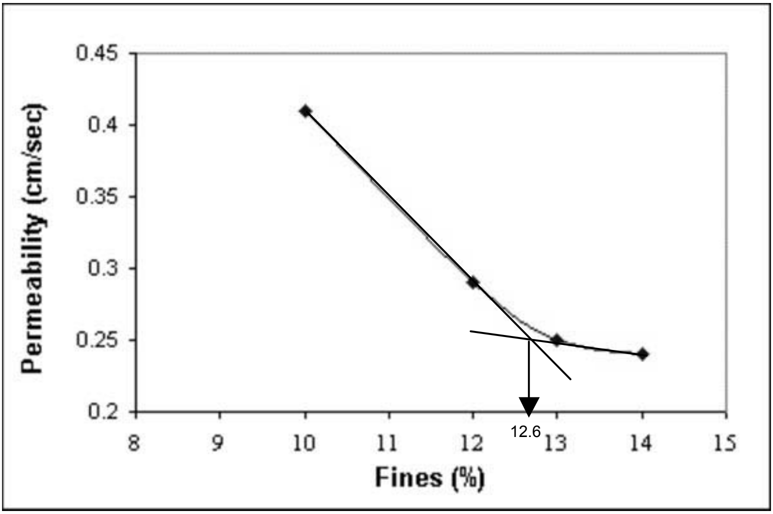

Figure 3: Permeability Test Result – Without DAMA

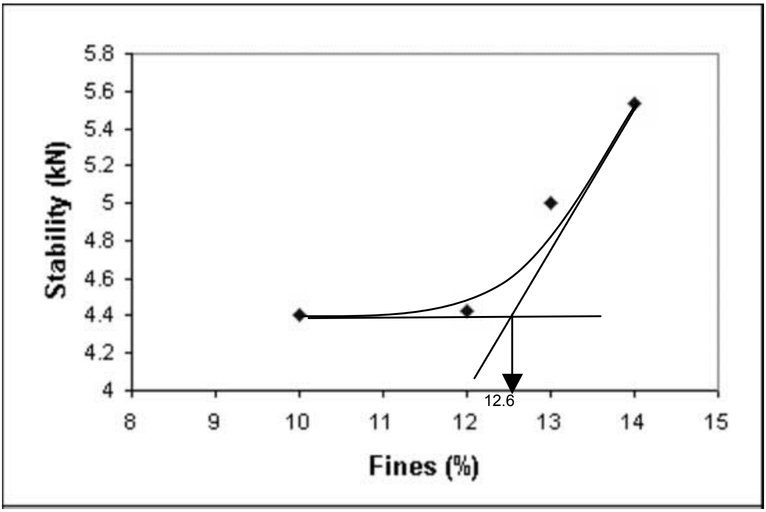

Figure 4: Stability Test Result – Without DAMA

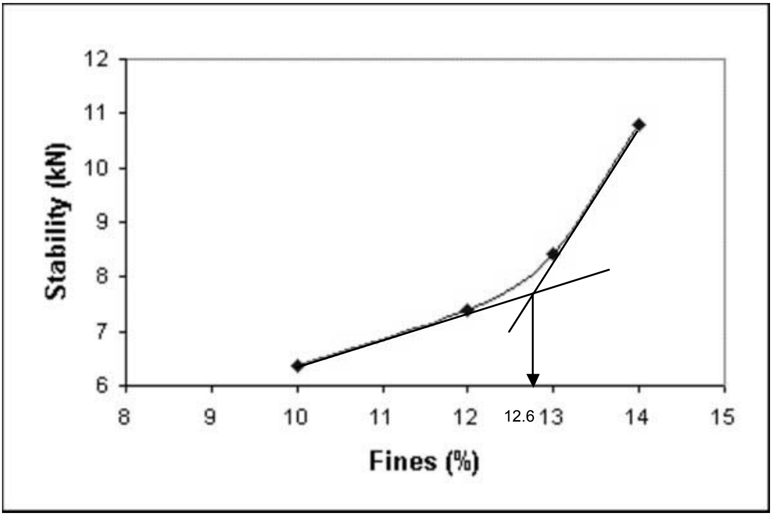

Figure 5: Stability Test Result-With DAMA

Binder Type	Percentage Fines to Optimise Stability	Percentage Fines to Optimise Permeability
Base 60/70	12.6	12.6
Base 60/70 + 1%DAMA	12.6	12.4

Table 2: Percentage Fines to Trade-Off Stability and Permeability

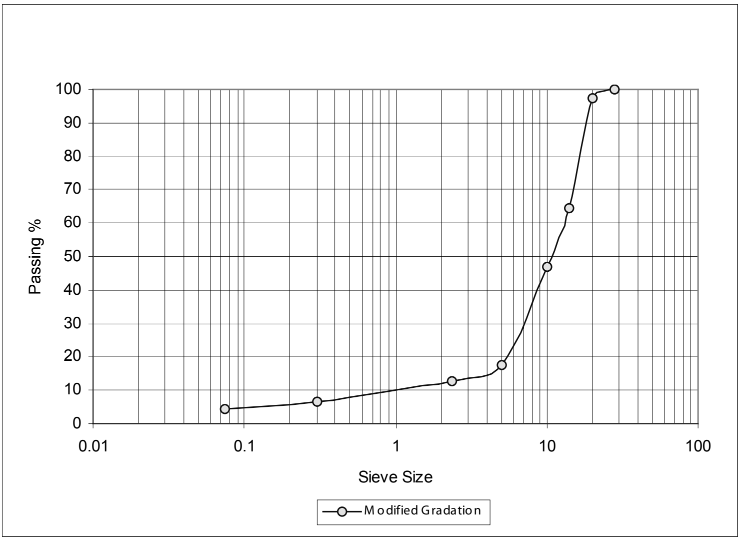

Figure 6: Particle Size Distribution of the Modified Gradation

5.2 Design Binder Content

The relationship between percentage retained binder content and percentage mixed binder content for mixes with and without DAMA are shown in Figures 7 and 8. For design purposes, the upper limit of the design binder content is equivalent to the target binder content which is the mixed binder content less 0.3%. For conventional bitumen mix without DAMA, the target binder content is 5.7%. However, the presence of 1% DAMA has the effect of increasing the target binder content to 6.1%.

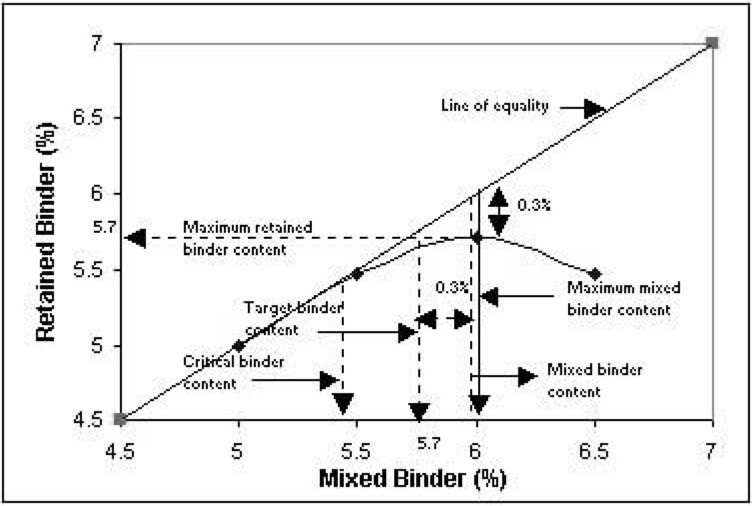

Figure 7: Binder Drainage Test Results - 60/70 Pen Bitumen

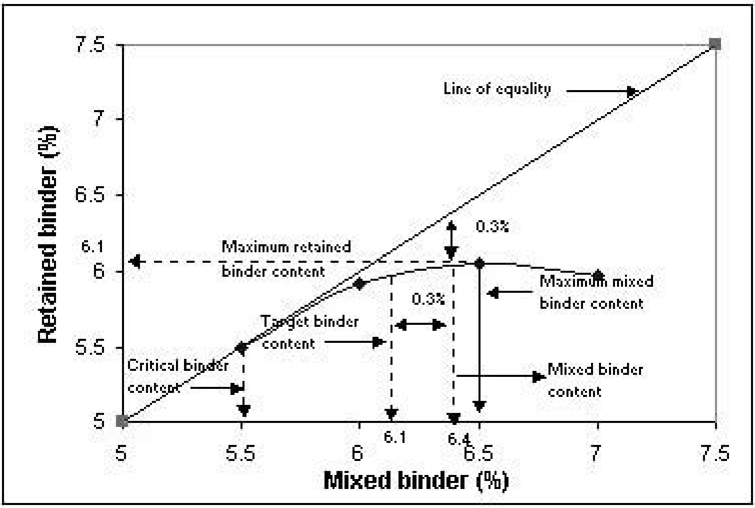

Figure 8: Binder Drainage Test Results - 60/70 Bitumen + 1.0% DAMA

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In the Cantabrian test, it is essential to determine the permitting abrasion loss at test temperature 29°C. The recommended maximum permitted abrasion loss value for freshly compacted specimens tested at 18°C, 20°C and 25°C are respectively 30%, 25% and 20%. A graphical relationship is shown in Figure 9. The permitting abrasion loss value at 29°C was determined by extrapolating this curve and equals 18%. This value is the permitting abrasion loss adopted to determine the lower limit of the design

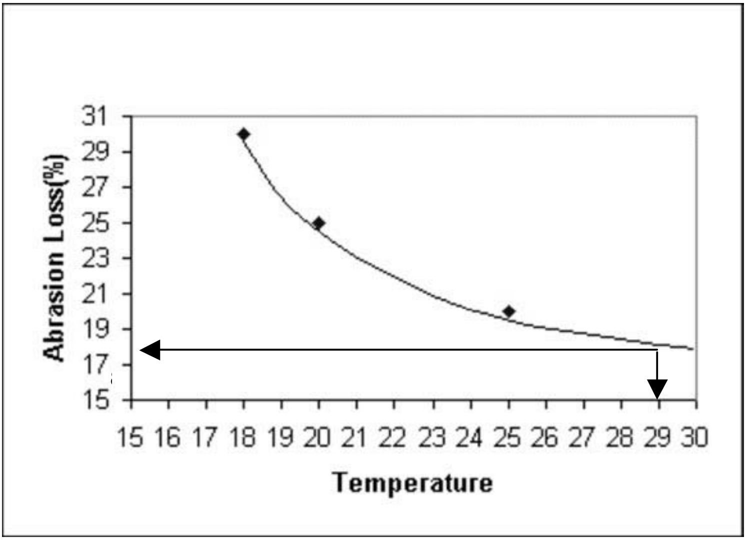

Figure 9: Relationship between abrasion loss limiting value versus temperature

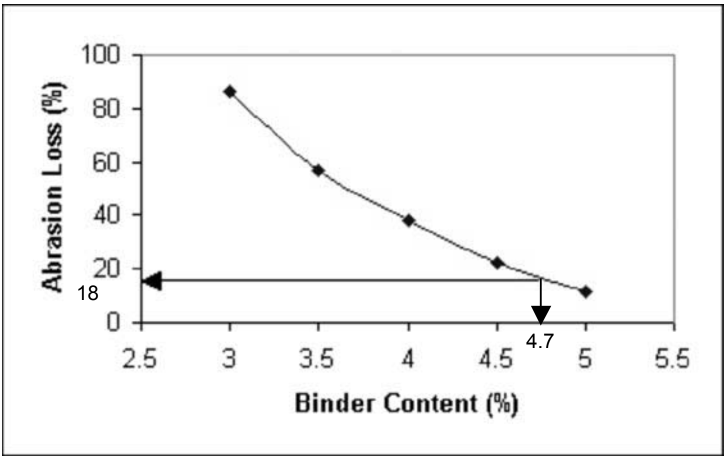

Figure 10: Abrasion Loss Results - 60/70 Bitumen

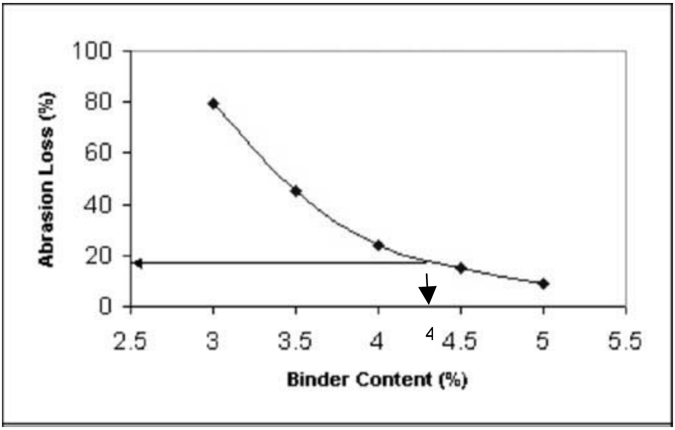

Figure 11: Abrasion Loss Results - 60/70 Bitumen + 1.0%DAMA

Types of Binder	Lower Limit	Upper Limit	Mean Design Binder Content	Mix Binder Contents Studied
Base 60/70 + 0%DAMA	4.7	5.7	5.2	4.7, 5.2 and 5.7
Base 60/70 + 1.0%DAMA	4.3	6.1	5.2	4.5, 5.0, 5.5 and 6.0

Table 3: Mix Design Binder Content in Percentage by Total Mass

5.3 Resilient Modulus and Marshall Stability

The results of the resilient modulus test for mixes prepared at binder contents shown in Table 3 are shown in Figures 12 and 13. A comparison between these graphs indicates that addition of 1% DAMA causes more than a two-fold increase in the resilient modulus.

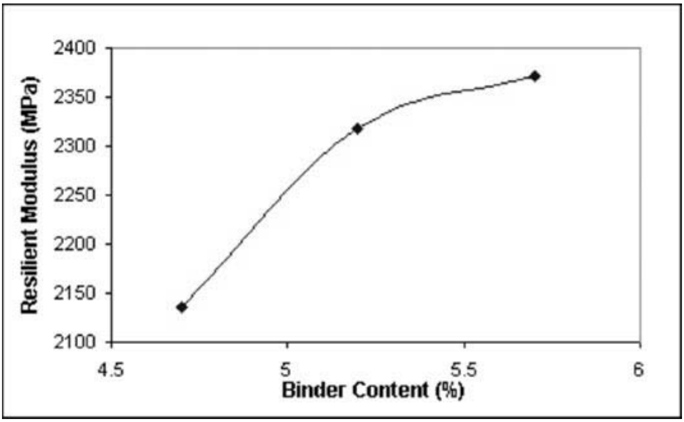

Figure 12: Resilient Modulus Test Results - 60/70 Bitumen

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The stability test results for both mixes can be compared from Figures 14 and 15. Both mixes, with and without DAMA, indicated stability values more than the required 5 kN. However, with the addition of DAMA, the stability value can increase by as much as up to 1.4 times compared to mixes without DAMA.

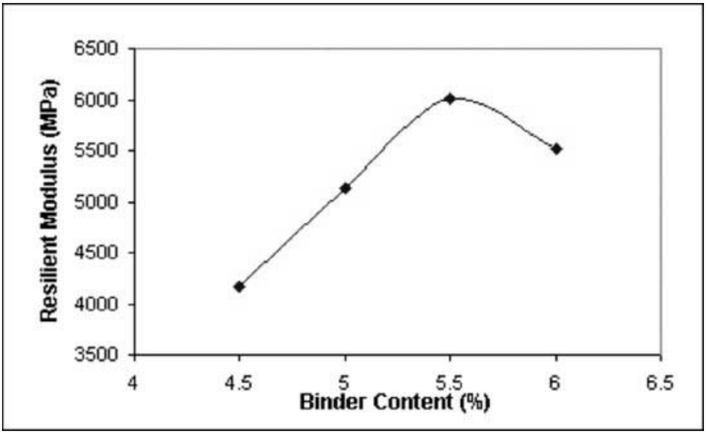

Figure 13: Resilient Modulus Test Results - 60/70 Bitumen + 1% DAMA

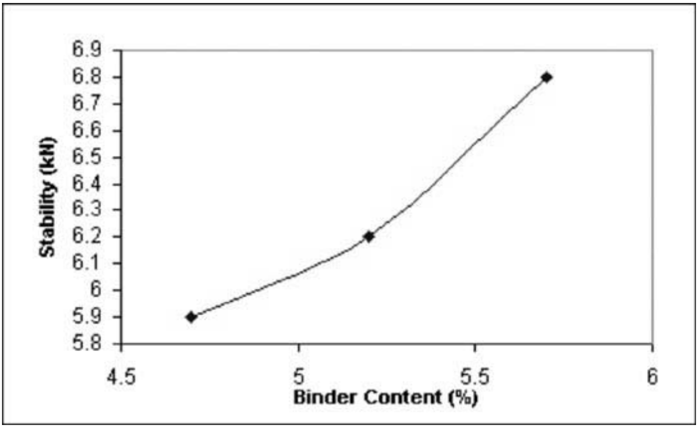

Figure 14: Stability Result Test - 60/70 Bitumen

6. CONCLUSIONS

1. A gradation developed in Korea has been modified to suit Malaysian quarry practice. The gradation was modified based on a trade-off between permeability and stability. The modified gradation consists of 12.6% fine aggregate fraction.
2. Porous mix properties prepared using the modified gradation with 60/70 pen bitumen satisfies the requirements stipulated in the Korean specifications. Mix properties can be further enhanced by adding 1% DAMA.

3. From the binder drainage test, the target binder content for conventional mixes is 5.7% while the presence of DAMA increases the target binder content to 6.1%.
4. From the Cantabrian test, conventional mixes requires 4.7% binder content to maintain 18% abrasion loss. With the addition of 1% DAMA, the binder content required to achieve identical abrasion loss reduces to 4.3%.
5. Addition of 1% DAMA causes more than a two-fold increase in the resilient modulus while stability values can increase up to 1.4 times.

REFERENCES

[1] Public Works Department Malaysia, *Malaysian Roads General Information 1999*, JKR 20401-0034-99, Roads Branch, Kuala Lumpur, 1999.

[2] Highway Planning Unit, *Quality of Roads in Malaysia - Road Safety*, HPU's report to the Economic Planning Unit, Prime Minister's Department regarding Malaysian Quality of Life Composite Index, 1998.

[3] W.B. Fuller and S.E. Thompson, *The Laws of Proportioning of Concrete*, Transactions American Society of Civil Engineers, 59, 66-172, 1907.

[4] F.N. Hveem, *Gradation of Mineral Aggregates for Dense Graded Bituminous Mixtures*, Proc. AAPT, Vol. 11, 315-339, 1940.

[5] L.W. Nijboer, *Plasticity as a Factor in the Design of Dense Bituminous Road Carpets*, Elsevier Publishing Co, 1948.

[6] G. Lees, *Rational Design of Aggregate Gradings for Dense Asphaltic Compositions*, Proc. AAPT, Vol. 39, 60-90, 1970.

[7] J.G. Cabrera. and M.O. Hamzah, *Agregate Grading Design for Porous Asphalt*, In Performance and Durability of Bituminous Materials, E & FN Spon, 1996.

[8] Darin Tech, *Ecophalt Quality Assurance Specification*, Presentation on Echophalt Pavement Technology to Malaysian Highway Authority, 15th November 2001.

[9] F.E.P. Jimenez and M.A.C. Perez, *Analysis and Evaluation of the Performance of Porous Asphalt: The Spanish Experience*, Surface Characteristics of Roadways: International Research and Technologies, ASTM STP 1031, W.E. Meyer and J. Reichert, Eds., Philadelphia, 512-527, 1990.

[10] M.E. Daines (1992), *Trials of Porous Asphalt and Rolled Asphalt on the A38 at Burton bypass,* TRRL Research Report 323, 1992.